Effect of Wheel Traffic and Tillage on Soil Water Infiltration in Annual Two-crop Region of Northern China Plain

Hao Chen*[1], Yali Yang[2]

College of Automotive Engineering, Shanghai University of Engineering Science, Shanghai 201620, China

pschenhao@163.com

Abstract

Controlled traffic with conservation tillage is an useful way to solve the problem of wheel track induced soil compaction. Effect of traffic and tillage on soil water infiltration and water use efficiency were conduced by experiments in Nothern China Plain with four treatments, including zero tillage with controlled traffic (NTCN), subsoiling with controlled traffic (STCN), zero tillage with random traffic(NT) and traditional tillage system with random traffic(CK). Results showed that, random wheel track caused significant soil compaction in the surface layer in annual two-crop region. Controlled traffic with conservation tillage reduced soil bulk density in 0-20cm soil layer, therefore improved water infiltration. Compared with non-controlled traffic treatments, controlled traffic with conservation tillage increased mean accumulative infiltration at steady infiltration by 67.4%. As more soil water was conserved in controlled traffic system, corp production was enhanced. Averagely, controlled traffic treatments increased annual yield by 3.8% compared with non-controlled traffic system Consequently, annaul water use efficiency increased 11.5% in controlled traffic system.In conclusion, controlled traffic farming has a better performance on soil and water conservation, and crop production.

Keywords

Controlled Traffic; Soil Physical Structure; Infiltration; Water Use Efficiency; Northern China Plain

Introduction

As the main agricultural production base, the North China Plain, which includes the provinces of Hebei, Henan, Shandong, Beijing and Tianjin, has about 18 million hectares of farmland (18.3% of the national total) and represents 20% of total food production in China (Sun et al., 2007). The main cropping system in the North China Plain is annual two-crop, summer maize and winter wheat, with an average total yearly yield of 15 $t.ha^{-1}$ (Li et al., 1997). Conservation tillage showed significantly higher performance in both soil conservation and crop yield in the region (Liu, 2004; He et al., 2009). Over 1 million hectares of farmland are now estimated to be under conservation tillage in arid and semiarid regions of northern China (McGarry, 2005).

Conservation tillage, in which crop residues are left on the surface to protect soil, increases water infiltration and reduces runoff. But degradation of the sub-surface soil by wheel traffic induced compaction can also reduce soil permeability, limit the benefits of residue cover and no-tillage, and generate major practical problems in conservation tillage. Random traffic caused 60% of the ground area being trafficked by wheel using minimum tillage systems and 100% for zero tillage systems (Radford et al., 2000). As less mechanical loosen methods were utilized in conservation tillage system, soil compaction due to wheel track was stressed out. Soil compaction induced by wheel traffic has adverse effects on soil properties and crop growth (Hamza and Anderson, 2005), significantly reduces soil porosity and water infiltration, therefore, reduce the effect of conservation tillage on crop productivity (Sadras et al., 2005; Wang et al., 2009). Serious soil compaction had been observed in previous studies on conservation tillage in annual two-crop region in North China Plain (Zhou, 2001), resulted in soil degradation and yield reduction, thus, endangered food security of China.

Wheel traffic effects on crops can be avoided in controlled traffic farming, where crop areas and traffic lanes are permanently separated to provide optimal conditions for crop growth (not trafficked) and traction (compacted). Studies comparing controlled traffic with wheeled soil have demonstrated significant improvements in soil infiltration properties, water content and crop productivity (Tullberg et al.,

2007; Wang et al.,2004; Bai et al., 2008). Previous study of controlled traffic farming in Loess Plateau showed obvious advantage in water infiltration and conservation (Bai et al., 2009). However, little is known about traffic effects on water infiltration in annual two-crop region in Northern China. The objective was to investigate the effect of wheel traffic on soil water infiltration in annual two-crop region in northern China.

Material and Methods

Site

Experiments was conducted at Daxing (39°7'N, 116°4'E) district, Beijing, from 2004 to 2007. Daxing lies in south Beijing in a semi-humid region 45m above sea level. Average annual temperature is 11.9°C with 186 frost-free days. Average annual rainfall is 526mm, in which more than 70% occurs during June-September. Double cropping system with winter wheat and summer maize is the main cropping system practiced in this region. Summer maize is seeded in early June and harvested in the middle of September. Winter wheat is then seeded in early October and harvested in the following June.

Soil is defined as silt loam according to the USDA texture classification system, which is low in organic matter (<1%) and slightly alkaline (pH 7.7). Soil in this region is generally described as porous and homogenous to considerable depth with limited variance across fields.

Experimental Design

At the beginning of the experiment in 2004, the entire field was ploughed to a depth of 40 cm to mix soil thoroughly and provided uniform soil condition in each experimental plot. The plot was 9 m wide and 90 m long. The experimental design was a random block with 4 replications. Four treatments were used: zero tillage with controlled traffic (NTCN), subsoiling with controlled traffic (STCN), zero tillage with random traffic (NT), and traditional tillage system with random traffic(CK). All treatments consisted of zero tillage with full residue retention for both wheat and maize.

The layout of the crop and permanent traffic lanes in controlled traffic treatments NTCN and STCN were shown in Fig.1, designed according to the characteristics of the local tractors and planters. Seven rows of winter wheat and two rows of maize were planted in 1.5 m beds. The width of each wheel track was 0.45 m, occupying 30% of the ground area. In NT and CK treatments, there was no permanent track lane. Wheat and maize were uniformly planted in each plot, 20 cm and 75 cm, respectively. The plot was 9 m wide and 90 m long. The experimental design was a random block with 4 replications.

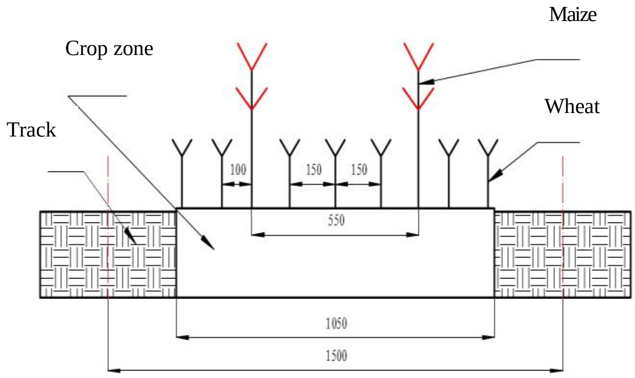

FIG.1 TRAFFIC LANES AND CROP LAYOUT FOR WHEAT AND MAIZE ON NTCN AND STCN (UNITS:MM)

The 2BMFS-2/7 no-till wheat-maize seeder, matched with a 48 kW tractor, was used for no-till seeding of both wheat and maize for NTCN and STCN treatment, which can confine the wheel traffic on the permanent traffic lanes during operation. After maize harvesting, the no-till seeder cleans strips by the knives in front of the tine openers, which can chop the residue without soil disturbance, and then no-till plants wheat. The press wheels are used to firm the seed and fertilizer at depths of 50 and 100mm, respectively. The seeder can plant 2 rows of maize or 7 rows of wheat simultaneously. For maize, the row space in the bed is 0.55m. For wheat, the seed openers were set to narrow and wide arrangement, in which row space beside the maize residue is 0.225m, the rest is 0.15m.

For NT and CK, wheat was planted by 2BMF-12 no-till wheat seeder with 0.2m row space, matched with a 48 kW tractor. After maize harvesting, the no-till seeder cleans strips by the knives in front of the tine openers, which can chop the residue without soil disturbance, and then no-till plants wheat. The press wheels are used to firm the seed and fertilizer at depths of 50 and 100mm, respectively. For maize planting, the 2BMFS-2/7 no-till seeder was used, by adjusting the maize opener space to 0.75m, which was most commonly used in this region.

Winter wheat is Jingdong-6 at a seeding rate of 120kg/ha, and summer maize is Jingyu-13 at a seeding rate of 37.5kg/ha, both of which are the most widely

used varieties in the region. Urea ($CO[NH_2]_2$), $(NH_4)_2HPO_4$ and KCl (K_2O content: 60%) were applied to provide 95kg N/ha, 75kg P/ha and 40kg K/ha as the basal N, P, K fertilizer at planting time. An additional 50kg N/ha was applied at first-node stage for winter wheat. Summer maize sowing density was seven plants per m^2 and a complete fertilizer (N-P_2O_5-K_2O) was applied at the rate of 85kg N/ha, 45kg P/ha, and 40kg K/ha at planting. Roundup (glyphosate, 10%) was used for weed control during summer maize growing season.

Soil Sampling and Preparation

Soil samples were collected in October each year (after maize harvesting and before wheat seeding). In each plot, one soil sample was formed by 6 sub-samples for soil bulk density and soil water content. The spatially replicated samples were individually analyzed for each treatment.

Bulk Density and Soil Moisture

In each plot, six random soil samples were taken using a 54-mm-diameter steel core sampling tube, manually driven into a 100-cm depth. The soil cores were split into ten sections: 0-0.1m, 0.1-0.2m, 0.2-0.3m, 0.3-0.4m, 0.4-0.5m, 0.5-0.6m, 0.6-0.7m, 0.7-0.8m, 0.8-0.9m and 0.9-1m. These samples were then weighed when wet, dried at 105 ºC for 48 h, and weighed again to determine bulk density.

Soil water content was measured by the gravimetric method by taking soil cores from the soil surface to a depth of 100 cm by 10 cm increments. The mean soil moisture content for all the treatments was computed as the soil moisture level of each depth.

Infiltration

The infiltration for both treatments was measured in October, 2007. Water infiltration was determined by the double-ring infiltrometer method (Bouwer, 1986), with a 30-cm inner diameter and 60-cm outer diameter cylinder. The infiltrometer was inserted for 10 cm into the soil on the experimental field (five replicates for each treatment). A constant water head of 20 mm was maintained in both rings, and the rate of infiltration was measured using discharge from a calibrated Mariotte bottle.

Wheat and maize grain yields were determined at 12% moisture content by manually harvesting 3 m length of rows taken randomly in each plot, with 4 replications. Seasonal evapotranspiration (ET) for individual plots was determined for each growing season using soil water balance equation:

$$ET = P + I - \Delta W \qquad (1)$$

where ET is the evapotranspiration of the growing season, P is the total growing seasonal rainfall, I is the irrigation, ΔW is the soil water change (final minus initial) from planting to harvesting, which was calculated by subtracting the total soil water content at 100 cm depth of soil profile. Annual Water use efficiency (WUE) was calculated as the yield of winter wheat and summer maize (t ha^{-1}) divided by the growing season evapotranspiration (ET).

Statistical Analysis

Mean values were calculated for each of the variables, and ANOVA was used to assess the effects of wheel traffic on the measured soil parameters and crop yields. Significance of the *F*-value was determined from ANOVA tables. Multiple comparisons of annual mean values were performed by the least-significant-difference method (l.s.d.). In all analyses, a probability of error smaller than 5% (P<0.05) was considered significant. The SPSS analytical software package was used for all the statistical analyses.

Results and Dicussions

Soil Bulk Density

After two years of experiment, controlled traffic treatmment showed lower soil bulk density in 0-30cm soil layer, and with significant difference in 0-20 cm soil layer (P<0.05), shown in Table 1.

TABLE 1 BULK DENSITY IN 0-40 CM SOIL LAYER FOR DIFFERENT TREATMENTS AFTER MAIZE HARVESTING （G/ CM³）

Treatment	0-10cm	10-20cm	20-30cm	30-40cm
STCN	1.21 ^{a}	1.35 ^{ab}	1.45 ^{a}	1.47 ^{a}
NTCN	1.25 ^{a}	1.32 ^{a}	1.45 ^{a}	1.47 ^{a}
Track	1.45 ^{b}	1.48 ^{b}	1.53 ^{a}	1.49 ^{a}
NT	1.34 ^{ab}	1.43 ^{b}	1.50 ^{a}	1.48 ^{a}
CK	1.38 ^{b}	1.45 ^{b}	1.51 ^{a}	1.46 ^{a}

Means within the same column in the same soil profile followed by the same letters are not significantly different at P<0.05.

In 0-10 cm soil layer, wheel traffic showed obvious soil compaction effect, in which track had the highest

value of soil bulk density. Controlled traffic treatments averagely reduced soil bulk density by 9.6%. Compared to CK, NTCN and STCN showed significantly lower value($P<0.05$), 9.3% and 12.3%, respectively. Compared to NT, NTCN and STCN reduced by 6.7% and 9.7%, without significant difference.

In 10-20 cm, average bulk density for NTCN and STCN (1.34g/cm^3) is 7.3% lower than that for NT and CK (1.44 g/cm^3), in which NTCN showed significantly lower value than CK($P<0.05$).

In 20-30 cm, acverage bulk density for NTCN and STCN was 3.7% lower than that of NT and CK.

Due to the wheel traffic, bulk density increased in nontrolled traffic treatments and track. This result was consistent with Seker and Isildar (2000) and Li et al. (2000) that the first passes of tractor will cause surface soil compaction. As soil deformation increased with the number of passes (Bakker and Davis, 1995), soil compaction went deeper in the second year. Due to the experiment time, the random traffic induced soil compaction was only on the surface layer.

Soil Water Infiltration

Treatment effects on soil infiltration were evaluated by comparing infiltration rates during the 180-min test. Initial infiltration rates (at 20 min) for both controlled traffic and random traffic treatments were similar, in which NTCN and STCN showed higher infiltration ability than NT and CK without significant difference. As time elapsed, NTCN and STCN showed significantly higher value on soil water infiltraiton than NT and CK ($P<0.05$).

The time to reach stable infiltration for NTCN, STCN, NT and CK were 65 min, 72.5min, 62.5minand 60min, in which STCN was significantly higher than NT and CK($P<0.05$). The steady infiltraiton rate for NTCN, STCN, NT and CK were 9.93 cm/h, 8.49 cm/h, 4.78 cm/h and 3.93 cm/h, respectively (Fig.3). Controlled traffic treatments significanlty steady infiltration rate than non-controlled traffic treatments ($P<0.05$), averagely 111.1%. Compared with CK, NTCN and STCN increased steady infiltration rate by 152.7% and 116.0%. Compared with NT, NTCN and STCN increased 107.7% and 77.6%.

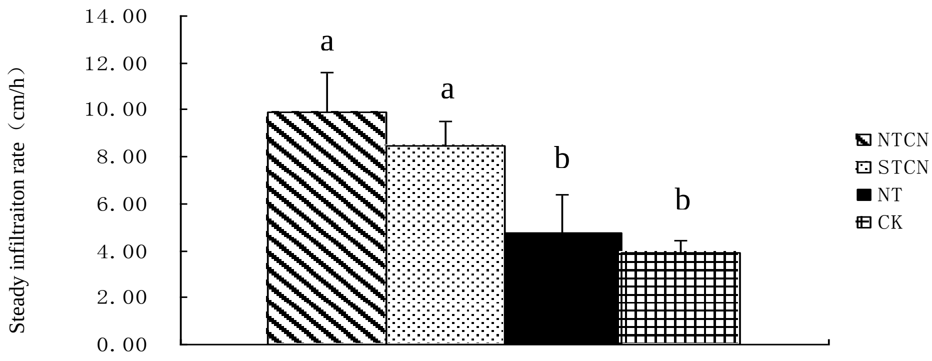

FIG.2 STEADY INFILTRAITON RATE FOR TREATMENTS

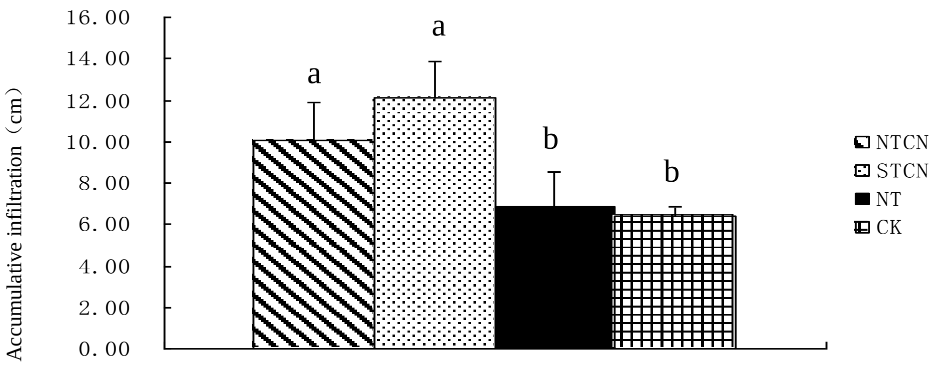

FIG.3 ACCUMULATIVE INFILTRATION AT STEADY INFILTRATION

Fig.3 was the accumulative infiltration at steady infiltraiton. Controlled traffic treatments showed significantly higher accumlation infiltration than non-controlled traffic treatments ($P<0.05$). The average value for controlled traffic treatments was 11.10cm, which was 67.4% higher than that of non-controlled traffic treatments. Compared with CK, NTCN and STCN increased 57.9% and 89.3%. Compared with NT, NTCN and STCN increased 47.1% and 76.4%. Subsoiling showed certain effect on water infiltration, STCN was 19.9% higher than NTCN, without significant difference.

By constraining wheel traffic in permanent lane, soil compaction in crop zone was significantly reduced. Consequently, infiltration rate and accumulative infiltration consequently significantly improved on controlled traffic plots. Random traffic on the NT and CK plots increased soil bulk density, which consistently reduced soil porosity in the top soil, especially the large pores. Therefore, water infiltration reduced significantly.Similar results on water infiltration were observed in southeastern Queensland of Australia (Li et al., 2001), and Loess Plateau of China (Bai et al., 2009), which demonstrated that the steady infiltration rate in controlled traffic plots was four to five times higher than that in non-controlled traffic plots.

WUE

Table 2 was the annual WUE for different treatments in the second year. As experiment time went, controlled traffic system increased soil physical property which result in higher soil water infiltration. Conquently, more water was conseved for corp production. Combined with the benefis of wide-narrow-row cultivation, higher yield was observed in controlled traffic treatments. Averagely, controlled traffic treatments increased annual yield by 3.8% compared with non-controlled traffic system, without significant difference. Compared with CK, NTCN and STCN increased annual yield by 3.0% and 5.1%. Compared with NT, NTCN and STCN increased by 2.5% and 4.7%.

Consequently, higher water use efficiency was observed in controlled traffic system, averagely 11.5% higher than non-controlled traffic system. Compared with CK, NTCN and STCN increase WUE by 7.5% and 12.6%, which increased 10.3% and 15.5% compared with NT.

TABLE 2 YEARLY WUE FOR DIFFERENT TREATMENTS

	P (mm)	*I* (mm)	*ET* (mm)	Annual Yield ($kg.hm^{-2}$)	Annual *WUE* ($kg.hm^{-2}.mm^{-1}$)
NTCN	507.4	296.6	713	12207	17.1
STCN	507.4	296.6	694	12461	17.9
NT	507.4	296.6	769	11907	15.5
CK	507.4	296.6	745	11852	15.9

Conclusions

Results from this study indicated that controlled traffic system improved soil structure and induced higher water infiltration.

(1) Compared to non-controlled traffic treatment, controlled traffic treatment decreased soil bulk density in the top soil layer.

(2) Controlled traffic increased accumulative infiltration at steady infiltration by 67.4%, compared with non-controlled traffic treatment.

(3) Due to higher water conservation capacity, controlled traffic system increase annual yield by 3.8% and annual WUE by 11.5%, compared with non-controlled traffic system.

Further reserach should be conducted in long-term to explore the benefit of controlled traffic system to solve the problem in annual two crops region.

ACKNOWLEDGEMENTS

This work was financed by National Science Fund Project "Research on mechanism of working resistance and energy consumption of no-till planting based on characteristics of residue-cutting and soil-breakage"(51175499), Shanghai Education Committee Project "Research on the soil/tire interaction" （13YZ109）, and Shanghai University of Engineering Science funding (nhky-2012-09).

REFERENCES

Bai, YH, Chen F, Li HW et al. "Traffic and tillage effects in wheat production on the Loess Plateau of China: II. Soil physical properties". Aust. J. Soil Res 46(2008):652-658.

Bai YH, He J, Li HW et al. "Soil Structure and Crop Performance After 10 Years of Controlled Traffic and Traditional Tillage Cropping in the Dryland Loess Plateau in China". Soil Science 74(2009):113-119.

Bakker DM, Davis RJ. "Soil deformation observations in a Vertisol under field traffic". Aust. J. Soil Res 33(1995): 817–832.

Bouwer H. "Intake rate: Cylinder infiltrometer". In Methods of Soil Analysis, Part I-Physical and Mineralogical Methods, No. 5, 2nd Ed. A.Klute (ed.). Soil Science Society of America Book Series, Madison, WI, pp. 825-844 (1986).

Hamza M, Anderson WK. "Soil compaction in cropping systems: A review of the nature, causes and possible solutions". Soil and Tillage Research. 82(2005): 121–145.

He J, Wang QJ, Li HW et al. "Effect of alternative tillage and residue cover on yield and water use efficiency in annual double cropping system in North China Plain".Soil Tillage Res.104(2009):198-205.

Li HW, Chen JD, Gao HW. A comparison of three tillage methods in dryland farming. Agric. Res. Arid Areas 15(1997): 7–11 (in Chinese).

Li HW, Gao HW, Chen JD et al. "Study on controlled traffic with conservative tillage". Trans. Chin. Soc. Agric. Eng 16(2000):73-77 (in Chinese).

Liu LJ. "Systematic experiments and effect analysis of all year conservation tillage in two crops a year region". Ph.D. Dissertation. China Agricultural University, Beijing, China (2004). (in Chinese).

Li YX, Tullberg JN, Freebairn DM. "Traffic and residue cover effects on infiltration". Aust. J. Soil Res 39(2001):239-247.

McGarry D. "The current status of conservation agriculture in China".(2005) http://www.adb.org/projects/PRC_GEF_Partnership/current-status.pdf.

Radford BJ, Bridge BJ, Davis RJ et al. "Changes in the properties of a Vertisol and responses of wheat after compaction with harvester traffic". Soil Tillage Res. 54(2000):155-170.

Sadras VO, Garry JO, David KR. "Crop responses to compacted soil: capture and efficiency in the use of water and radiation".Field Crops Research, 91(2005): 131-148.

Seker C, Isildar AA. "Effects of wheel traffic porosity and compaction of soil". Turkish J. Agric. Forestry 24(2000): 71–77.

Sun HY, Zhang XY, Chen SY et al. "Effects of harvest and sowing time on the performance of the rotation of winter wheat-summer maize in the North China Plain". Soil Tillage Res. 25(2007): 239–247.

Tullberg J N, Yule DF, and McGarryAD. "Controlled traffic farming from research to adoption in Australia". Soil Till. Res. 97(2007):272-281.

Wang QJ, Chen H, Li HW et al. "Controlled traffic farming with no tillage for improved fallow water storage and crop yield on the Chinese Loess Plateau".Soil Tillage Res. 104(2009): 192-197.

Wang, X. Y., H. W. Gao, H. W. Li et al. Tillage, traffic and residue impacts on soil and water loss from dryland in China. In Conservation Tillage & Sustainable Farming. Z. C. Wang, H. W. Gao (eds.). China Agricultural Science and Technology Press, Beijing, China, pp. 481-490(2004).

Zhou XX. The experimental study on mechanized conservation tillage system in two crops a year region. Ph.D. Dissertation. China Agriculture University, Beijing, China (2001) (in Chinese).

Hao Chen was born in China in 1980. He obtained his Ph.D. degree in agricultural engineering in 2008. His research interests include conservation tillage, terramechanics and soil mechanics and related fileds. Currently, he acts as associate professor in College of Automotive Engineering, Shanghai University of Engineering Science